GRIZZLY CREEK GLACIER ICE-CORED MORAINE SYSTEM

PETER G. JOHNSON

Department of Geography and Regional Planning, University of Ottawa, Canada

ABSTRACT. The degradation of the Grizzly Creek ice-cored moraine system is controlled by the activity of meltwater streams within the moraine system. Although it would be possible to calculate a base rate for degradation due to thermal processes the dominance of the drainage controls on location and rates of degradation processes throws doubts on the usefulness of detailed thermal approach to the problem. The study of thermal processes is made more complicated by the great variability of material conditions on the moraine and the lack of accurate year round climatic data.

Introduction

Grizzly Creek, a small alpine valley in the Kluane National Park of the south-west Yukon Territory (Fig. 1) was selected in 1974 as the site for the study of a number of glacial and periglacial landforms. The site was chosen because of the variety of landforms present in the valley, because of its small dimensions offering the opportunity to study altitudinal effects on various processes and because of its ease of accessibility from the Arctic Institute of North America's Base Station at Kluane Lake. As part of this program, the Neoglacial and Recent ice-cored moraine system of the Grizzly Creek Clacier was studied with the aims of: (A) a further understanding of the processes of degradation of an ice-cored system, (B) a study of the hydrology of an ice-cored system, and (C) determination of the pattern of deglaciation from the Neoglacial maximum position as a behavioural comparison of a small glacier fed from a local ice cap with the major valley glaciers fed from the St. Elias Icefield and which have been studied by Denton and Stuiver

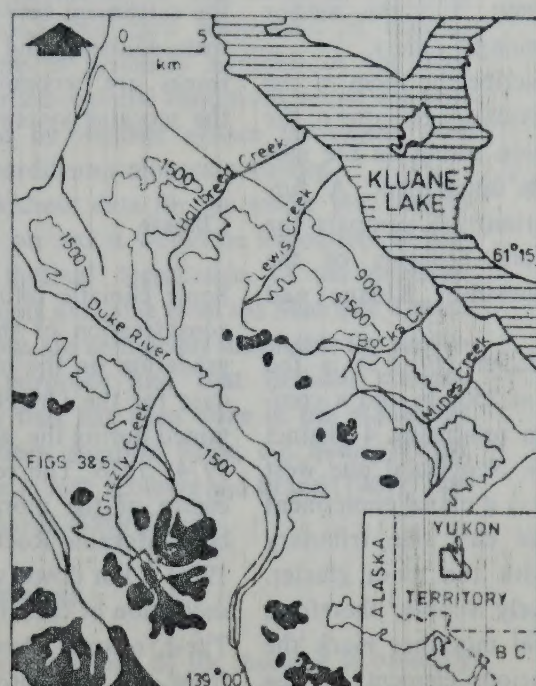

Fig. 1. Location map

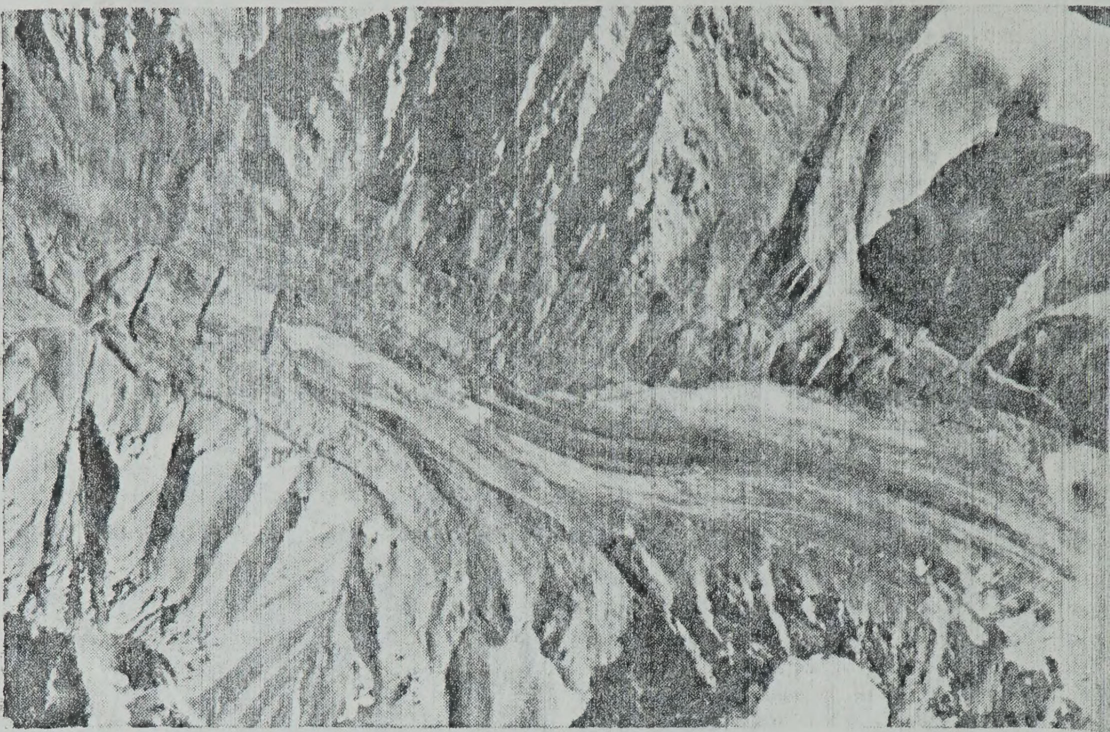

Fig. 2. Aerial photograph of the Grizzly Creek Glacier and Moraine. A.238 95 – 248 Original photograph supplied by Surveys and Mapping Branch, Department of Energy, Mines and Resources

(1966), Rampton (1969), and the author (Johnson, in prep.) amongst others.

The paper will describe the form of the moraine system and its drainage pattern, the processes of degradation acting on the moraine and the controls upon them. A further paper (in preparation) will compare the Neoglacial and Recent histories of the Grizzly Creek, Kaskawulsh, Kluane and Donjek Glaciers.

Grizzly Creek Glacier (Fig. 2) is fed from a small icefield at 2500 m and a complex cirque at 2200 m producing 4 distinct flow lines. During the Neoglacial one west side hanging glacier was a major component of the system but an east side tributary was not confluent with the main glacier. The system is relatively simple, therefore, and a series of medial moraines mark the boundaries of the various elements of the flow. Due to slight geological variations in the catchment between Greywacke, iron rich metasediments and shales, these medial moraines are recognisable through much of the moraine system.

Climate

Some climatic information is necessary for consideration of the thermal effects of degradation on the moraine system. The only data for the Grizzly Creek area were obtained during the summer field seasons of 1974 - 1976. The records were taken at the centre of the moraine system and on the large Moraine Rock Glacier (Johnson 1974, 1975) 2 km down valley in order to give an indication of climatic change along the river. These records show substantial differences from the meteorological stations in the Shakwak Trench at Burwash Airport, D

struction Bay and the Arctic Institute Camp at mile 1054 and it would be impossible to draw any inferences, apart from very general trends, about climatic conditions in the valleys of the Kluane and Donjek Ranges from this data. The climatic inferences drawn by Webber (1974) in the A.E.S. report on the Kluane National Park are obviously very wide of the mark based on the short period Grizzly Creek summer records.

TABLE 1. DAILY AVERAGE CLIMATIC PARAMETERS

Climatic parameter	1974	1975	1976
Solar rad. cals/cm²	194.4	181.5	207.6
Precipitation mm	43.0	46.0	46.0
Max. temperature °C	6.7	6.04	9.28
Mean temperature °C	−1.74	−1.98	0.13
Mean temperature °C	1.85	1.78	4.19
Humidity R.H. %	73.06	74.45	83.72
Wind run km	216.2	223.3	214.2
Down valley %	54.29	52.25	71.58
Up valley %	34.75	27.63	19.00

A brief summary of the records will be presented here because of the bearing on the thermal degradation of the ice-cored moraine system. The data presented in Tab. 1 are the daily averages for six week field seasons in June, July and August of 1974, 1975 and 1976. Although 1974 and 1975 were very similar in average conditions, they were very different in the trend to the conditions through the field seasons. 1974 was consistent through the season whereas 1975 experienced a very warm first part and a very cold second part. 1976 was in general a much warmer summer although precipitation and wind run averages were the same as 1974 and 1975. In 1976 the wind direction was dominated to a much greater extent by down valley winds as a response to the warmer conditions. The response of degradation processes on the moraine in the field seasons was erratic and was apparently a function of the climatic trends during the season and the previous winter conditions, particularly snowfall and its duration. Thermal degradation processes on the moraine will be discussed later.

Accepted models of valley climate did not apply in Grizzly Creek during the field seasons. The wind system did not conform to glacier diurnal or katabatic models. Although some diurnal trends are occasionally apparent, usually associated with very stable regional conditions, the normal condition was dominance of one direction for long periods. This rare occurrence of diurnal systems is probably a result of the very disturbed regional conditions which are produced by weather system movement over the cordilleran mountain barrier.

Without data for the whole year measured on site it would be impossible to predict thermal degradation of the moraine. The data available from the Shakwak Trench stations are completely unsuitable for predictive purposes and that detailed climatic study that has been done in the mountains has been summer work, e.g. Benjey (1970); Brazel (1968); Kolberg and Brazel (1969); Taylor Barge (1969).

Morphology

The morphology of the moraine is basically simple (Fig. 3). The medial moraines apparent on the glacier at the present can be traced through to the terminus of the moraine system due to geological variations from the lateral deposits and from the medial moraine between the Grizzly Creek Glacier and a hanging tributary glacier on the west side. The entire moraine system is ice cored. Ice core exposures are widespread and elsewhere the nature of the sub-surface drain-

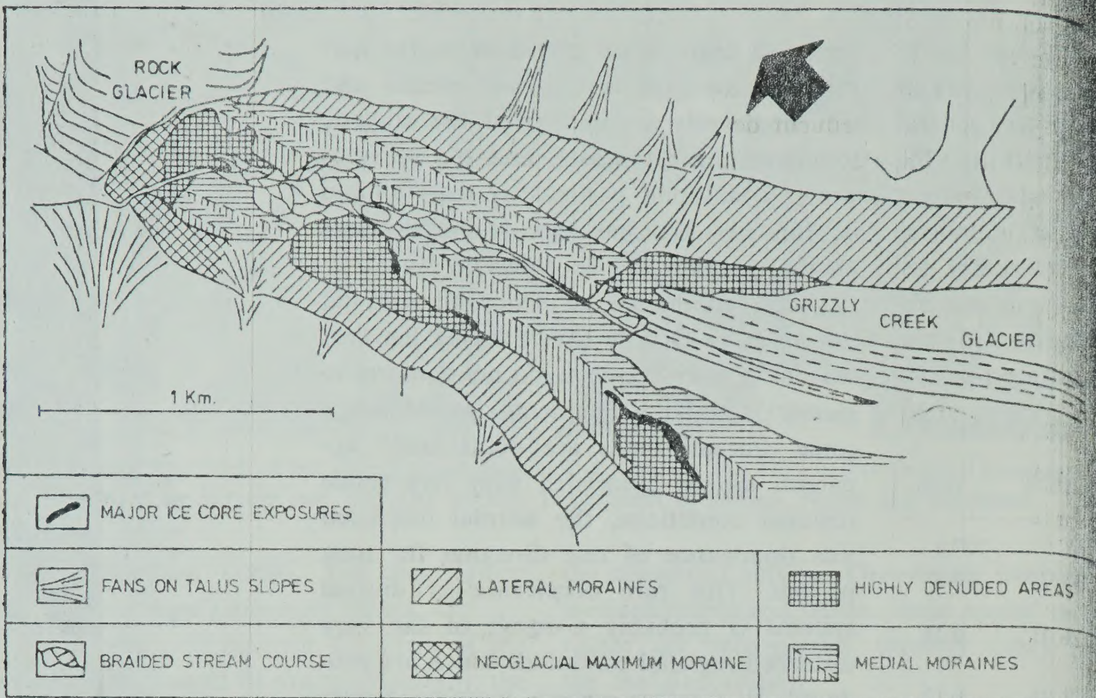

Fig. 3. Morphology of the Grizzly Creek Moraine

age indicates continuity of the ice core. Where exposed the ice core consists of glacier ice with remnants of sedimentary structures, foliation and debris bands. The thickness of the surficial materials is variable ranging from less than 5 cm on the medial moraines near the glacier to over 150 cm on the proximal side of the downvalley terminus. Slope angles over the ice core also have a wide range of values from over 30° on the fresher medial moraines and the lateral moraines to generally less than 10° on the older parts of the system.

There are four very heavily denuded areas on the moraine. The area on the west side of the system mid-way between the glacier terminus and the moraine terminus was denuded between 1950 and 1974 as photographic evidence for the 1950's shows that the medial moraine is still identifiable through this area but by 1974 almost complete reworking of this area had occurred. The area of the east of the present glacier terminus is still undergoing rapid degradation as is the area to the west of the terminus where there is only a very thin cover of ablation debris. The area close to the moraine terminus is an old degradation area which has recently been reactivated by a change in the main drainage stream (see Drainage Pattern). In all four of these classes the degradation is directly related to stream activity as are many of the more localized areas of degradation.

As can be seen from Fig. 2, the Neoglacial maximum moraine is still clearly demarcated on its distal side except for two or three small areas where concentrations of talus material down chutes has locally overridden the moraine. The extent of the talus in these localities is due to mass movements such as avalanching and mud flow activity, both of which have been observed in this area. The terminus of the moraine system

shows little evidence for the recent operation of degradation processes except for some surface cracks which have appeared over the subsurface drainage course initiated in 1976.

Between the moraine system terminus and the glacier three stable ice marginal positions can be tentatively identified (Fig. 2). The first position just proximal to the outer terminus caused meltwater to drain over the northern edge of the moraine and erode the lateral channel between the moraine system and the rock glacier (Fig. 3). Retreat from this position caused the concentration of the drainage through the gap at the apex of the moraine until the subsurface channel opened in 1976. A second position is marked by small cross valley moraine remnants which rise up to 1 m above the outwash plain and have caused a small step in the stream profile. The third position is the most distinct with a large cross valley ridge which produces a large step in the profile of the stream. Since this position the glacier has undergone progressive stagnation and retreat.

Neoglacial activity

In the post Pleistocene retreat of the ice, the Grizzly Creek Glacier retreated up valley of the present ice-cored moraine extent. This is evident from the truncation of the east side rock glacier and the west side alluvial fan at the moraine terminus position. The author has suggested that the glacier stagnated rapidly in the post Pleistocene period leaving a thick ablation till deposit in the middle valley but only a few lateral deposits in the upper valley. A modern day analogy of a tributary of the Kaskawulsh Glacier was suggested (Johnson, in preparation). Into the Hypsithermal period with a change from periglacial to temperate conditions, there was a period of formation and then stagnation of rock glaciers, the formation of alluvial and talus fans with the subsequent development of soil and vegetation complexes on these features occurred prior to the deposition of a layer of volcanic ash from the Mt. Natazhat source on the Yukon Alaska border. A date for this ash layer of 1425 ± 50 years B.P. was calculated by Stuiver, Borns and Denton (1964) by bracketing C^{14} dates. Soils and vegetation development continued after the deposition of the ash layer but with the climatic deterioration of the Neoglacial period the glacier started to readvance and the more severe periglacial conditions caused reactivation of parts of the rock glaciers in the valley. Denton and Stuivers work on the Donjek and Kaskawulsh Glaciers indicate that the ice was retreating from the maximum Neoglacial position by the beginning of the 18th century (Denton and Stuiver 1966, 1967) but the date of attainment of the maximum position is more problematic. At maximum extent the glacier had cut into a rock glacier and a large alluvial and talus fan and the lateral meltwater drainage established deep courses which have not been closed by any recent activity on the two forms. The Neoglacial period would not appear, therefore, to have produced conditions conducive to talus formations.

In the post maximum period the glacier has been steadily receding but with the three possible stable phases. These three more stable phases of the glacier would correlate with the general pattern of deglaciation of the Kaskawulsh, Kluane and Donjek Glaciers (paper in preparation).

Thermal degradation

Two controls on the degradation of the ice cored moraine system were investigated. First the effect of heat transfer through the

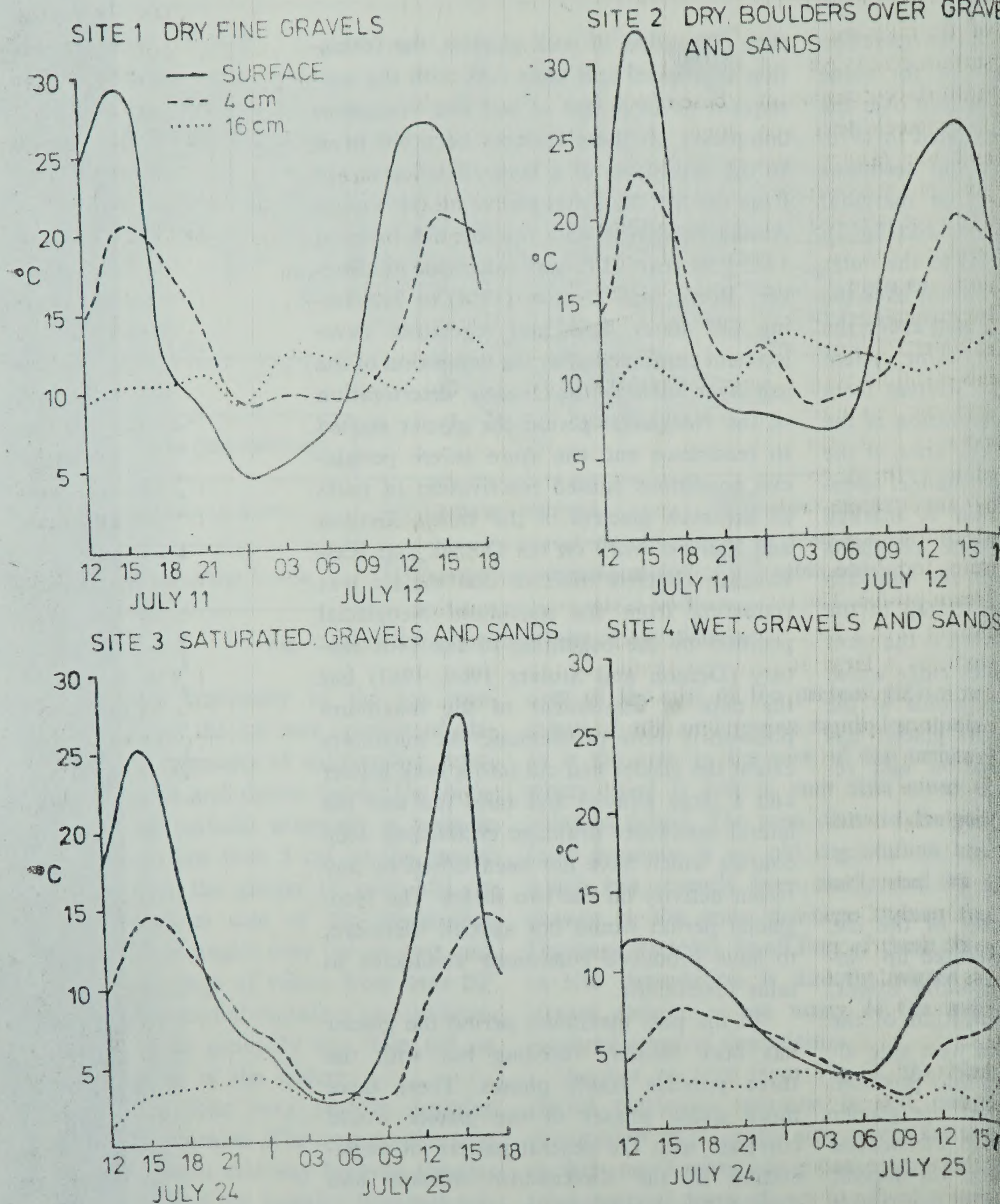

Fig. 4. Temperature depth curves at four sites

materials causing melt of the ice core and second effects of meltwater drainage systems on the moraine.

The moraine is characterized by a great variety of material composition, mineralogy, moisture content, exposure to solar radiation and to wind and hence it is difficult to make any general statements about thermal de

gradation. Four contrasting sites were chosen for evaluation of heat flow effects on the ice core. Two sites were on the main terminus ridge of the moraine. Site 1 was composed of the fine gravels and coarse sands, probably overlying till at depth, and was generally dry. Site 2 was till with a coarse surface litter of boulders and generally had low moisture contents. At both these sites the material depth exceeded 100 cm. The other two sites were on the west medial moraine where material thicknesses were always less than 100 cm, and as little as 5 cm in places. At these two locations, sites 3 and 4, the material was wet to saturated through the whole of the field season. Using the simple approaches of Sellers (1965) and Scott (1964) thermal diffusivity values ranged from 0.002 to 0.005 which indicate that in all cases the daily heat input at the surface should have some effect on the ice core. Characteristic temperature depth curves for the four sites are presented in Fig. 4.

Of the sites monitored there were only indications of process response at sites 3 and 4 where some downslope movement on the ice surface was indicated by slip ridges. More active movements were detected where slope angles were very steep, 25° to 30°, and where there was minimal debris cover over the ice. In general degradation due to ice core melt beneath materials was slight. In 1976 no measurements were possible due to the heavy winter snow accumulation, which masked the surface for most of the season.

The greatest effects of thermal degradation were noted in the early part of the 1975 season with exceptionally warm conditions and little winter snow lying on the surface. Very significant rates of degradation occurred wherever the ice core of the moraine system was exposed. In most cases, however, the exposure of the ice was due to fluvial activity and exposures were only maintained for long periods by efficient removal of material by fluvial activity at the base of the ice exposure. After exposure and under conditions of efficient debris removal rates of degradation of the ice faces up to 100 cm per week were measured. Correlation of daily rates of degradation with climatic parameters showed little of significance but indicated trends to the following expected relationships:

– increased degradation rates during penetration of the upvalley winds,

– decreased degradation rates with the occurrence and strength of the down valley winds (off glacier),

– increase in the slip component of degradation during and after heavy precipitation events,

– no apparent correlation with incoming solar radiation or sunshine records, emphasizing the importance of radiation balance figures.

Drainage pattern

It is apparent that the rates of degradation of the moraine system are far greater than what might be termed the base rate due to thermal processes and that the drainage system and its fluctuations is the major controlling factor on the higher rates of degradation. It is arguable that detailed studies of thermal degradation offer little to the understanding of landscape production in areas of stagnant ice. The drainage pattern of Grizzly Creek moraine system is shown in Fig. 5.

The drainage system consists of three elements: 1) the main drainage from the Grizzly Creek Glacier, 2) drainage from the west side hanging glacier and 3) drainage off the talus slopes and any elements originating on the moraine itself.

The Grizzly Creek Glacier drainage has both lateral and subglacial components. In

the early part of the 1974 field season the drainage was predominantly lateral with the greatest flow along the eastern margin. This discharge was eroding into and through the ice core of the moraine for a distance of 100 m below the glacier terminus and has resulted in a highly denuded area with a large number of small ice core exposures. Late in 1974 the lateral stream on the east side diverted into a subglacial course about 500 m from the glacier terminus and the glacier discharge dropped dramatically for 30 mins. until a hydrostatic blow-out occurred at the glacier terminus. This sent a flood wave down valley and deposited a gravel bed up to 100 cm thick over 1000 m^2 of snow bank at the glacier terminus. This subglacial resurgence has been the dominant glacier drainage stream since 1974. Below the glacier the stream followed a braided course through the moraine and discharged from the moraine via a steep cut through the Neoglacial Maximum moraine. This course, which from photographic evidence had been dominant for 30 years and probably since the formation of the system, was maintained till early 1976. In 1976 the stream split just inside the Neoglacial Maximum moraine with some discharge still occurring through the old channel and some being diverted into a small pond which periodically drained through the ice core of the moraine, resurging through the terminus of the rock glacier to the north. By late 1976 the drainage events of this lake became almost diurnal in occurrence and this course was taking progressively more of the discharge. With the drainage events the pond extended 10 times its original dimensions during a period of 6 weeks with the rapid erosion of the ice core beneath the outwash materials. By 1977 all of the discharge was following this course and the stream was rapidly incising into the old outwash plain exposing up to 8 m of stagnant glacier ice beneath only 10 - 20 cm of outwash gravels. The head-

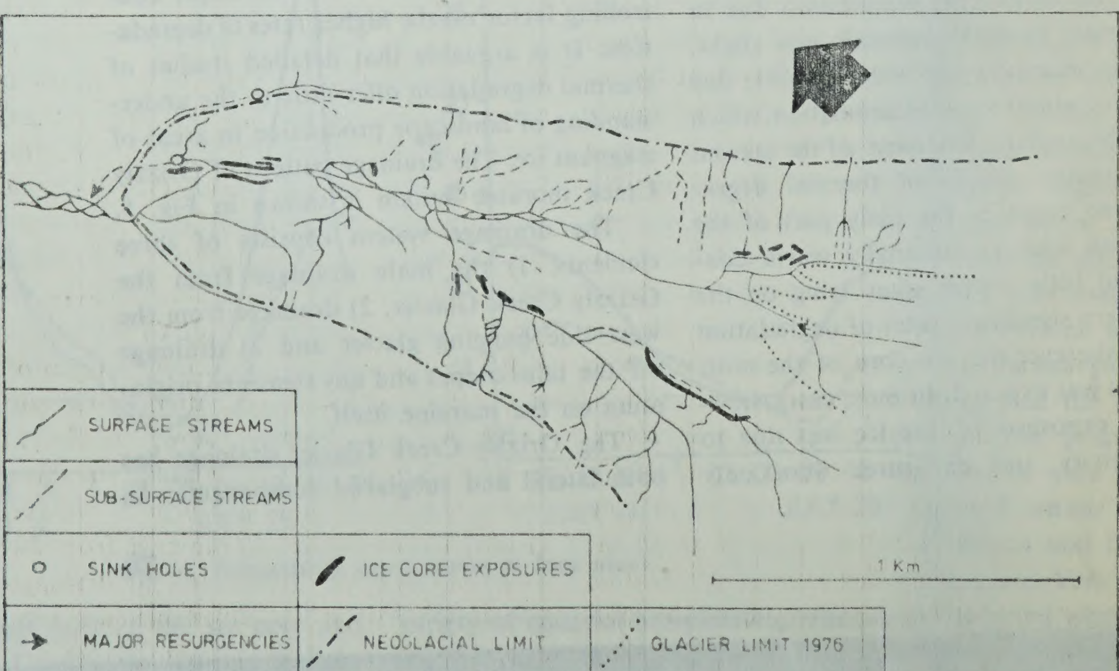

Fig. 5. Map of drainage pattern of the moraine system

ward erosion of the cut into the ice core proceeded at up to 20 m per week to the end of the field season and resulted in the degradation of most of the old braided outwash stream bed. More degradation occurred in one year, therefore, than had occurred in the period since deglaciation.

Drainage from the west side hanging glacier has also been responsible for considerable amounts of degradation. Large active ice core exposures exist along both arms of this drainage system and are inducing rapid degradation of the medial moraine. Short term rates of retreat of these ice faces of 1 m per week have been recorded and the long term effects can be estimated by comparison of the 1956 aerial photograph cover with the present situation. In 1956 the area marked as highly degraded in the central section of the system (Fig. 3) was still fresh in form and this hanging glacier component of the drainage was confluent with the main drainage close to the maximum terminal moraine. In 1974 the stream was confluent with the main drainage 200 m upstream (Fig. 5) and the intervening area had been considerably degraded. In the 1974 - 1977 period the stream has been mainly subsurface in course and has been producing further degradation of the medial moraine by exposure and maintenance of ice exposures and by collapse of the moraine over subsurface channels.

Most of the small streams developed on the moraine or off the talus have had relatively degradational effect due to the limited occurrence of ice core exposures along their courses. Frequently these streams flow in subsurface courses, on or within the ice core. On both the east and the west sides of the system especially on the steeper slopes of the lateral moraines localised increases in degradation occur along the stream courses and are marked by mudflow structures.

Rates of degradation

In order to obtain information on the rates of retreat of ice faces where they were exposed a number of sites were mentioned. Pegs were set into the ice at intervals back from the ice face and measurements were taken on a regular basis through the season. No sites showed the same patterns or rates of retreat and no correlation to the basic climatic parameters was found. As an illustration of rates of degradation the average figures from two sites measured in 1974 and 1975 are presented in Tab. 2. These remarkable contrasts occurred between seasons when the average climatic conditions were identical (Tab. 1).

It is suggested that the major contrast between the two seasons was the amount and duration of the winter snow cover and its effects on meltwater activity. The large, early season meltwater generation of 1975 produced a much greater impact on the moraine than the small and more evenly spread generation of 1974. By constrast in 1976 snow cover was deep and melted very late

TABLE 2. ICE FACE RETREAT RATES (cm)

	Site A		Site B	
	1974 (30 days)	1975 (35 days)	1974 (30 days)	1975 (35 days)
Average total retreat	41.4	326.3	50.7	185.0
Range	21 - 72	225 - 450	30 - 73	145 - 220
Daily average	1.38	9.3	1.69	5.28

and slowly so that although statistically it was a much warmer field season (Tab. 1) most of the ice core sites were not exposed until late in August. Hence very little degradation occurred in the 1976 season.

Conclusions

It is apparent that a study of the thermal degradation of ice-cored system is complicated due to the variability of the parameters which must be considered and also only gives a base rate for the degradation of the system. On the Grizzly Creek Glacier moraine the meltwater discharge is responsible for the initiation and continued activity of degradation processes and that amount of degradation caused by stream activity is considerably greater than that caused solely through thermal processes. As a result the melt out landscape is controlled by the stream activity.

Estimation of the rates of degradation is virtually impossible except on a short term basis given information on potential discharge from winter snow cover and possible summer season climatic trends.

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Assoc. Prof. P. G. Johnson, Department of Geography and Regional Planning, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada.

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